"Substitute specification

METHOD AND APPARATUS FOR CONTROL OF VIEWING ZONES

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This invention is concerned with the field of three-dimensional imaging and particularly with the control of the position in space of the viewing zones required for an observer to view a three-dimensional image without the use of special viewing aids.

BACKGROUND

International Patent Application WO94/20875 [PCT/GB94/00405] (Street) describes apparatus in which two two-dimensional perspective images, provided by conventional liquid crystal display (LCD) panels, are combined with the aid of a semi-transparent mirror, so that each eye of the observer sees a different perspective but in the same location. This causes the brain to fuse these perspectives into one three-dimensional image. The principal purpose of the aforementioned invention is to avoid the need for the observer to wear special spectacles. International Patent Application WO97/22033 [PCT/GB96/03014] (Street) apparatus is described which provides, simultaneously, both right and left eye images from a single LCD. Three-dimensional images provided in this way are generally referred to as autostereoscopic.

In certain embodiments described in [of] both of the aforementioned publications, WO94/20875 and WO97/22033 [inventions], the position of the viewing zone for each of the respective eyes of the observer is controlled by the precise relative positioning of two complementary optical components. The first of these comprises a regular array of juxtaposed cylindrical lens elements, or lenticles, fixed to and supported by a transparent substrate and is commonly referred to as a lenticular screen. The second and complementary component, which is positioned behind and close to the lenticular screen, comprises an array of light blocking regions on a transparent substrate. These blocking regions may take the form of long strips, as in WO94/20875 [PCT/GB94/00405], or they may be arranged in a chequered fashion, as in WO97/22033 [PCT/GB96/03014]. European Patent Application EP 0 788 008 (Naosato et al.) describes apparatus similar to that of WO97/22033, although it is silent in respect of how to achieve observer tracking. This is a key objective of the current invention and is referred to, in principle, in both WO94/20875 and WO97/22033. Therein, by [By] providing both the lenticular screen and the blocking pattern, referred to hereinafter as a barrier screen, with a vertically tapered structure and controlling the relative position of one with respect to the other, the lateral position of a viewing zone and its distance from the apparatus may be controlled. Such control is required at right

angles to the long axes of the lenticles for horizontal displacement of the zone and along the axis of the central lenticle (vertically) for a relative change in local scale between the lenticular and barrier screens. This change of local scale gives rise to a change in the convergence of light leaving the apparatus from adjacent lenticles and, thus, adjusts the point of convergence and the distance of the viewing zone from the apparatus.

The required accuracy in the positioning of the lenticular screen, relative to its corresponding barrier screen, is high, as the optical magnification of the pattern of the barrier screen, which gives rise to the viewing zones, may be as high as 300 : 1. Typically, relative and rapid positioning to an accuracy of a few microns is desirable in the lateral direction, whereas the orthogonal positioning requirement, will be less demanding. If a conventional control loop was applied to each component, each would be permitted one degree of freedom, all others being constrained to the required precision. In addition, the structural stability of the system, as a whole, would have to be high, so as to avoid changes of scale due to temperature changes or mechanical creep in the position of components.

A proposed method for controlling the position of a lenticular screen relative to an LCD to provide an autostereoscopic image is described in UK Patent Application GB 2317771 A (Woodgate et al.). The features of the embodiments described in this prior art include, inter alia, firstly the need to analyse visible or infrared images of the observer and to use these signals to control, directly, the alignment of the lenticular screen relative to the image providing LCD, secondly one or more detector assemblies which are positioned with great accuracy relative to the pixel array of the LCD. Preferably the photodetectors are integrated within the LCD's construction. The aforementioned PCT Applications seek, in their preferred embodiments, to use standard LCD devices which have not been specifically adapted for stereoscopic use. Furthermore, these LCD's are typically positioned in front of a structured light source, thus being capable of conventional use, and do not form part of the observer tracking system.

Further general background to the state-of-the-art which has relevance to the current invention may be found in EP 0 743 552 (Fogel et al.). Here the objective is to register a segmented print, comprising many different perspectives of a three-dimensional scene, very precisely behind a lenticular screen prior to lamination for viewing by an observer. This is achieved by having a regular array of reference marks on the image bearing print, outside the viewable area, and observing the Moiré pattern between these small patterns and the regular array of cylindrical lens elements that make up the lenticular material. Two such patterns positioned at the

top and bottom of the image to be registered can allow both lateral registration and the removal of any rotational error. There is no provision for adjusting the relative scale of the pitch between the segments of the print and that between the elements of the lenticualr screen. Furthermore, the process does not provide an absolute lateral position, but a multiplicity of solutions, as registration is only required with respect to the nearest lens element of the screen.

SUMMARY OF THE INVENTION

It is an object of the current invention to provide a system for the control of the lateral position of a lenticular screen relative to a corresponding barrier screen, to provide a stable and accurately located viewing zone, without the need for the structural stablity which would be demanded using independent control means for each of these components.

It is a further object of the invention to provide a convenient means for controlling the distance of the viewing zone from the apparatus.

It is another object of the invention to provide automatic compensation for any changes in relative scale or positioning, due to mechanical creep or thermal changes.

Thus, according to the invention, apparatus for the encoding and control of relative position of components within an autostereoscopic display system comprises a first substrate having a first plurality of light blocking and light transmitting regions comprising in aggregate a first object pattern in an object plane; a second substrate positioned relative to and/or spaced from said first substrate; first convergent means fixed relative to said second substrate for substantially collimating in a first orthogonal plane, said orthogonal plane being orthogonal to said object plane, light from points of said first object pattern to provide or subsequently form, in use, a first image pattern corresponding to said first object pattern at a first image plane; and first image detection means positioned at said first image plane for capturing a first image portion comprising a portion of said first image pattern, characterised in that said first image portion contains sufficient image data to unambiguously define its location within said first image pattern along a first image axis corresponding to a first object axis at said first object pattern whereby, in use, the relative position along said first object axis of the first substrate relative to the second substrate is determined.

Preferably the second substrate is a lenticular screen; the first convergent means comprises a first cylindrical lens element of said screen; and the first orthogonal plane is orthogonal to the longitudinal axis of said first cylindrical lens element.

Advantageously elongate aperture means is fixed with respect to the lenticular screen and arranged to block light which passes through lens elements adjacent to the first cylindrical lens element. The aperture means may comprise an opaque coating on a portion of the front surface of the lenticular screen

The first object pattern on the first substrate may comprise alternate, juxtaposed light blocking and transmitting stripes having respectively a selection of widths and gaps and arranged so that, in use, the locating, with the first image detection means, of at least three boundaries between the images of light transmitting and light blocking stripes within said first image portion provides the data to unambiguously define the identity of one of said stripes and the location thereof along the first object axis relative to the first convergent means. Preferably a particular sequence of widths and gaps is not repeated within the object pattern.

Advantageously the first substrate has a second plurality of light blocking and light transmitting regions comprising in aggregate a second object pattern in the object plane; second convergent means fixed relative to the second substrate for substantially collimating in a second orthogonal plane, said second orthogonal plane being orthogonal to said object plane, light from points of said second object pattern to provide or subsequently form a second image pattern corresponding to said second object pattern at a second image plane; and second image detection means positioned at said second image plane for capturing a second image portion comprising a portion of said second image pattern, in which said second image portion contains sufficient image data to unambiguously define its location within said second image pattern along a second image axis corresponding to a second object axis at said second object pattern whereby, in use, the relative position along said second object axis of the first substrate relative to the second substrate is determined.

In certain embodiments the first image portion's location along the first image axis provides a first ordinate; the second image portion's location along the second image axis provides a second ordinate; and said first and second ordinates are combined to provide the position of the first substrate relative to the second substrate.

Preferably the second substrate is a lenticular screen having a tapered structure in which the first convergent means comprises a first cylindrical lens element of said screen and the second convergent means comprises a second cylindrical lens element of said screen spaced from said first lens element. The first and second patterns may be tapered, so that the width of each stripe reduces from one end to the other, and the first object axis and the second object axis may be inclined with

respect to eachother so that the position of the first substrate relative to the second substrate can be provided in two orthogonal directions.

Advantageously, means for controlling the relative positions of the substrates in the two orthogonal directions is provided. In preferred embodiments the image detection means includes one or more linear CCD arrays. A sequence of three transitions or boundaries between transmitting and blocking regions can unambiguously define the location of these boundaries within the pattern of which they form part.

DESCRIPTION OF PREFERRED EMBODIMENTS

The invention will now be described with reference to Figures 1 and 2 in which:-

Figure 1 shows a section through position encoding apparatus constructed in accordance with the invention, together with a diagrammatic illustration of encoded position data, derived therefrom.

Figure 2 shows how two degrees of freedom for relative positioning may be provided in accordance with the invention.

A typical arrangement for encoding the position of a lenticular screen relative to a barrier screen is shown in Figure 1. A lenticular screen 1 is positioned in front of a barrier screen 2. A plurality of light transmitting regions and light blocking regions, shown respectively as light and bold line segments on the front surface 3 of barrier screen 2, are arranged side-by-side in an alternating fashion, thereby being juxtaposed to form in aggregate a defined pattern. One of the lenticular screen's lenses 4 is isolated from its neighbours by a narrow aperture in plate 5. This is typically considerably longer than its width, given the cylindrical nature of the lenticular screen's lens elements (lenticles). Lenticle 4 is a convergent element which collimates light from points on surface 3 to pass through the aperture in plate 5. Surface 3 may therefor be regarded as an object plane at which is situated an object pattern. The collimating action of the lenticle occurs in a plane substantially orthogonal to both the object pattern and the longitudinal axis of the cylindrical lenticle 4. In this embodiment of the invention, lenticle 4 has a focal length of about 3 mms and collimates the light from the pattern and, so, a lens 6, with a focal length of approximately 20 mms reimages this light to form, in one dimension, a magnified image of part of the pattern at surface 3 on an image capture device in the form of a linear CCD array 7. This is the image detection means required to analyse features within the image. [In other embodiments] <u>It</u> [it] is possible to arrange for some additional convergence of light in the orthogonal plane to form the image of the pattern, following passage through the lenticle, in

which case lens 6 would not be required, [whilst the action of] as the lenticle would reimage the light whilst remaining [remain] substantially a collimating element [one].

Many different configurations in terms of scale and magnification of the object pattern are possible. In the example given the pattern comprises light providing stripes and dark spaces having gap sizes and widths which substantially equate to an integral multiple of one quarter of the pitch between the lens elements of the lenticular screen. A typical pitch between lenses in an autostereoscopic display system would be 0.6 mm, though larger and smaller lens pitches may conveniently be employed. If the whole of the pattern at surface 3 were to be imaged simultaneously onto the CCD's surface and lens element 4 behaved as a perfect imaging element, then the width of the pattern to be imaged would be approximately 6 mms and the field of view of this element would have to be greater than 90° if the whole of the image were to be viewed simultaneously. If the image formed had no distortion, then the CCD's signal and the image would correspond to the schematic representation 8. In practice, this is found to be impractical and is not necessary, as a portion of the image of the pattern is sufficient. Light transmitting gaps form image components such as 9 and 10. A blocking region creates a dark space 11. The relative widths of the blocking regions, the sizes of the gaps between them provided by the transmitting regions and the order in which these light and dark regions are arranged unambiguously defines which portion of the image of the pattern is captured on the CCD. In fact, only three transitions are required for the particular pattern illustrated to extract the data needed to unambiguously define their exact position within the pattern to the accuracy that the CCD can provide. The pattern illustrated comprises three intrinsic relative dimensions for both the width of blocking regions and the gaps between them. No sequence comprising three transitions or boundaries between a transmitting gap or blocking region, thereby comprising one dark region having a width and one light gap of a particular relative size, is repeated within the pattern as a whole. Representing a light gap as being one (1L), two (2L) or three (3L) units in magnitude, and likewise the dark regions as having one (1D), two (2D) or three (3D) units of width, the particular pattern, used in the example given, comprises the following groupings of three transitions, each comprising, in full, a dark and a light region:-

2L3D, 3D3L, 3L2D, 2D1L, 1L3D, 3D2L, 2L1D, 1D1L, 1L2D, 2D2L, 2L2D, 2D3L, 3L1D, 1D3L, 3L3D, 3D1L, 1L1D, 1D2L

As the barrier screen is moved laterally 12 with respect to the lenticular lens 4, the pattern shifts on CCD 7, and different groupings of transitions may be used to determine the relative lateral position of the barrier screen 2 with respect to the lenticular screen 1. More precisely, the relative position of the object pattern on surface 3 of the barrier screen is determined relative to the axis of the lenticular element 4. In practice, this is conveniently done by locating the midpoint of the light region which is closest to a predetermined location on CCD 7, this point being substantially at the intersection of the optical axis of the lens element and the surface of CCD 7. To allow for transitions from one midpoint to the next, the practical field of view of lens element (4) must be such that any two neighbouring light regions can be brought into view simultaneously. In the illustrated example, this requires a field of view of approximately 23°, which is easily accommodated. Typically a conventional diffuse light source 13 is positioned behind the barrier screen 2.

Figure 2 illustrates how the use of two patterns on the barrier screen may be used to determine the position of the latter relative to the lenticular screen in front of it in two orthogonal directions. For the sake of diagrammatic convenience, the two patterns 20 and 21 are shown close together and at considerable magnification. In practice, a considerable gap would be typical, with one pattern on the left hand side of the barrier screen and the other on the right hand side. Two apertures 22 and 23 are shown schematically. For the sake of clarity the lenticular screen, which is situated inbetween the apertures and the barrier screen, is not included. Each of the apertures is positioned to block light passing through lenticles adjacent to a different one of two spaced lenticles on the lenticular screen. This provides respectively a first and a second convergent cylindrical lens element for forming seperate images of the spaced patterns at different image planes associated with corresponding CCD detectors. Also illustrated is a deliberate taper between the two patterns 20 and 21. As the barrier screen is moved up and down relative to the apertures, there will be a component of movement orthogonal to the long axis of the stripes within each pattern and different portions thereof will become central to the field of view of the corresponding CCD (as provided in Figure 1 and not shown in Figure 2). Each of these detection arrangements has a different orthogonal plane defining a direction or axis (A1, A2) of measurement at the object pattern and at the corresponding image plane. When the lenticular screen and the barrier screen have an intrinsically tapered structure, as employed in the embodiments of the aforementioned WO94/20875 [PCT/GB94/00405] and WO97/22033 [PCT/GB96/03014], it is the up and down relative motion which controls the convergence of the light transmitted through the lenticular structure

and thus the distance or longitudinal positioning of the resulting viewing zone or zones. The directions of the measurement axes are inclined with respect to eachother at the plane where the object patterns are located. This enables two different ordinates to be obtained and these provide, in a simple manner, a measure of both the lateral relative motion between the lenticular and the barrier screen and their relative motion in the orthogonal (vertical) direction. By employing oppositely tapered patterns, as illustrated, the change in relative position derived from each CCD is opposed when the relative motion is vertical and has the same sign when the motion is lateral. Thus, by averaging the resulting relative motions, an accurate lateral position is derived and, by establishing the difference in the two relative positions detected, a term proportional to the relative vertical movement is obtained. The proportionality constant depends on the inclination of one pattern relative to that of the other. It will be clear that a small angle of inclination between the two ordinate axes, as illustrated, can provide a meaurement in the two required orthogonal directions, but that the result will have greater accuracy for horizontal motion than for the vertical. Conveniently, this is completely compatible with the requirements of an autostereoscopic display system, where lateral positioning of the viewing zones must be accurate and fast, but where there is considerable tolerance in the longitudinal positioning thereof.

The height of the apertures 22 and 23 may be small, as illustrated, if horizontal relative motion between lenticular and barrier screen is achieved by moving the lenticular screen relative to the detection system. However, in the case of the preferred embodiment of WO97/22033 [PCT/GB96/03014], it is the lenticular screen which is moved in a vertical direction relative to the overall assembly and, in this case, the height (or length) of apertures 22 and 23 must accommodate the full extent of this motion. In such embodiments, it is convenient to form the apertures on the surface of the lenticular screen by providing an opaque coating or layer on its surface. This has a clear region on that part of the surface which comprises the image forming lenticle.

Simple actuators such as stepper motors, DC motors or voice coils (not shown) may be used to position the two substrates (lenticular and barrier screen) relative to one another. Since position feedback for both directions of relative motion is obtained directly from the relative positions of the two screens or substrates, substantial accuracy is maintained without high cost. Even dimensional changes due, for example, to manufacturing tolerances or temperature effects are accommodated. This is particularly true of the tapered structure, in which a relative change of scale of the barrier screen or lenticular screen would

automatically be compensated for by the necessary correction in the relative positions of these two components.

It will be clear to those versed in the art that the principles of this invention are not limited to the control of the relative position of a lenticular screen with respect to a corresponding barrier screen. Other components requiring optical position monitoring and/or control might benefit from similar arrangements. Although the object patterns illustrated comprise transparent regions, which would typically be back lit with a diffuse light source, it would be quite practical to replace such regions with appropriately shaped light emitting elements such as, for example, might be provided using light emitting polymers. In general the regions which are light blocking prevent light from leaving points from their location at the object plane. These are, therefore, light inhibiting. Conversely, the regions which are light transmitting could be replaced by regions which are light emitting, whether this light be generated at the object plane or elsewhere and re-emitted at its surface. This would include specularly reflected light. These are therefore in general light providing regions. Any reference herein to light blocking regions or stripes is therefore deemed to include light inhibiting ones and any reference herein to light transmitting regions is deemed to include light providing ones.